Biobased Products and Bioenergy

Biobased PLA Polymers Grow New Markets for American Corn Products

Collaboration between U.S. Department Leads to Industrial Partnership

In a unique collaborative effort, Cargill, Incorporated, and The Dow Chemical Company in 1997 formed a 50/50 limited liability company, Cargill Dow LLC, to develop and market polylactic acid (PLA) polymers, which are made from corn. PLA polymers are renewable, compostable alternatives to hydrocarbon-based thermoplastics, such as polyethylene, polystyrene, and polypropylene.

In creating this new venture, Cargill brought its expertise in the process technologies needed to support development of PLA, whereas Dow Chemical brought its polymer science, applications technology, and global customer base. After several years of effort, Cargill Dow LLC broke ground in spring 2000 on a 300-million-pound-per-year PLA plant in Blair, Nebraska. The plant started up in late 2001 and began commercial production in May 2002.

The U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) and the Department of Commerce's National Institute of Standards and Technologies (NIST) have provided assistance to organizations working to develop momentum for PLA at a time when market risk was high and commercialization uncertain. Early federal investments established the fundamental science behind PLA and built technologies around that science to move PLA into commercial production.

Prior to Cargill Dow's formation, DOE/EERE funded research at the National Renewable Energy Laboratory (NREL) and Coors/Golden Technologies to identify low-cost biomass feedstocks for use in fermenting sugars into lactic acid. Cargill and Dow Chemical's direct interest in PLA began with a grant the two companies received from NIST's Advanced Technology program to study the fundamental properties of PLA. This research gave Cargill and Dow Chemical

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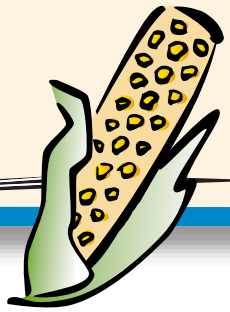
the opportunity to identify PLA properties that could lend the polymers well to specific commercial applications. At the same time, Cargill was engaged in research through DOE/EERE with the University of California-Berkeley, Lawrence Berkeley National Laboratory, US Filters, Omni Interests, and Advanced Separation Technologies to develop a technology that improved the separation of lactic acid from the other substances produced by fermenting biomass feedstocks (such as carboxylic acids, alcohols, and amino acids), a necessary step in the production of PLA.

In addition to the research investment contributed by federal sources, Cargill Dow LLC also benefited from several economic incentives provided by the State of Nebraska, including a five-year state and local tax moratorium, secured low-interest rate loans, and non-financial assistance in purchasing land adjacent to needed biomass resources.

What Makes PLA So Special?

Fossil fuel-based thermoplastics (which PLA polymers can replace in many cases) are typically used in such applications as packaging, fabrics, films, and coatings. The major difference between fossil fuel-based thermoplastics and PLA polymers is that the former are derived from petroleum, and the latter are derived from corn. Although many fossil fuel-based thermoplastics can be recycled, very few are biodegradable. Many products made from PLA polymers are compostable.

PLA is derived from lactic acid, which is formed by the fermentation of sugars and starches. One of the best renewable sources of these starches is corn and corn stalks (corn stover). Once lactic acid is produced, it undergoes a chemical reaction process (polymerization) that causes two or more molecules to combine and form larger molecules that contain repeating lattice structures, to produce PLA.



Biorefinery Concept Maximizes Feedstock Resources

Catalyzed by DOE-supported research, Cargill Dow LLC is investigating the industrial biorefinery concept for the Blair plant to extract additional value from the feedstocks it uses. Industrial biorefineries take in multiple biomass feedstocks and by using multiple process streams, produce a combination of fuel, power, and other products with high regional value. These "mini-plants" within the facility are cost-effective because they are located close to their feedstock source.

This innovative approach will allow a bioenergy plant to hydrolyze and ferment an additional feedstock stream of corn stover to produce lactic acid, ethanol, and power. The Blair facility is located within 50 miles of 2–5 times the biomass feedstock resources needed to meet the plant's capacity.

Benefits of Polylactic Acid (PLA) Polymers

The current plastics market is approximately 100 billion pounds per year. By 2020, the potential market for PLA is expected to be greater than eight billion pounds per year of the total plastics market. The PLA market will not displace current applications of fossil-based plastics; instead, it will capture growth in those markets through the creation of new applications.

On the basis of an annual production of eight billion pounds, PLA has the following potential benefits:

Energy

- *Reduce dependence on imported petroleum—206 trillion BTU fossil fuel savings per year*

Environment

- *Renewable—made from corn-based feedstocks*
- *Clean—improves air quality through reduced volatile organic hydrocarbon (VOHC) emissions, particulates, and greenhouse gas emissions*
- *Compostable, depending on formulation*

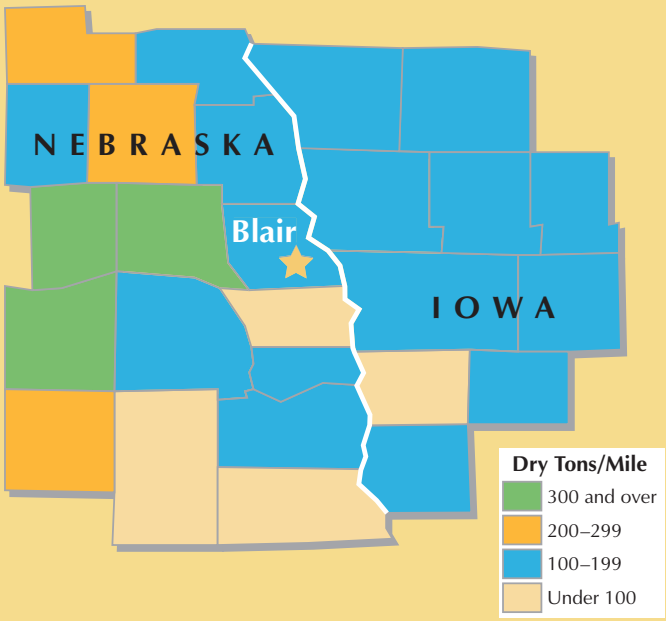
Economy

- *Develops new value-added markets for American farmers*
- *Creates new industries and jobs*

Product

- *Resistant to grease and oil*
- *Helps retain flavors and prevent odors*
- *Possesses good aesthetic qualities (gloss, clarity)*
- *Strong under stress*
- *Sealable at low-heat temperatures*
- *Conducive to melt fabrication processes (thermo-forming, extrusion, blown film processing, fiber spinning, injection molding)*

Corn Stover Available Within 50 Miles of Cargill Dow PLA Plant in Blair, Nebraska



PLA Development Timeline

1994 — DOE's Office of Energy Efficiency and Renewable Energy (EERE) funds research conducted by Coors/Golden Technologies and the National Renewable Energy Laboratory (NREL) to examine promising feedstocks to ferment sugars into lactic acid.

1995-1998 — National Institute of Standards and Technology's (NIST's) Advanced Technology Program (ATP) awards a grant to Cargill and The Dow Chemical Company to explore the fundamental properties of PLA.

Taking PLA Polymers from Concept to Commercialization

Cargill Dow LLC is focusing initially on producing materials for two product segments—packaging and fibers—at the Blair plant, and exploring additional product line opportunities:

- For the first product line, the company will work together with Unitika and Sony to produce PLA for use as film packaging for Sony mini-discs.
- For the second product line, Cargill Dow has joined forces with Mitsubishi Plastics, Sumitomo Rubber Industries, Inc., and Dunlop Japan Ltd., to launch PLA as a new, environmentally friendly packaging option for Dunlop golf balls.
- Cargill Dow LLC is also pursuing efforts with Fiber Innovations Technology, Inc., and Parkdale Mills to produce PLA fibers and yarns that can be used in activewear clothing manufactured by Interface, Inc., and The Woolmark Company.
- To identify additional clothing applications for PLA, Cargill Dow LLC is working with Unifi, the world's largest producer and processor of textured yarns.

Industry	Product	Key PLA Properties
Fiber	*Clothing*	*spun fibers; dye fixing*
	Carpet tiles	*spun fibers; dye fixing; compatible with backing*
	Filtration	*semi-permeable*
	Soil erosion control	*biocompatibility with soil; stiffness; tensile strength*
Packaging	*Films/wrapping*	*high clarity; high stiffness; thin extrusions; twist retention; low-temperature seal*
	Containers	*rigidity; thermoforming; compatible with substrates*
	Bottles	*clear; compostable*

Randy Howard, president and CEO of Cargill Dow LLC, explains the strong appeal of the company's NatureWorks™ PLA polymers:

"People buy products based on value and performance. What we have done is expanded the definition of both. To us, value and performance are not just how products themselves perform, but should also encompass the raw materials they come from, how they are made and where the products will go at the end of their useful lives. This is the kind of sustainable vision we are applying to our business model. Our goal is to create plastics today without compromising the earth's ability to meet the needs for tomorrow."

Howard goes on to elaborate on the impact of PLA in the marketplace, which has a lifecycle that reduces fossil fuel consumption by up to 50%:

"The benefits of items made from NatureWorks PLA are already being experienced by many consumers around the globe. Companies like The Coca-Cola Company, Dunlop Pacific, Sony Pacific, Pacific Coast Feather Company and Monogram are already realizing significant value based on the resulting products' performance and unique story."

1997 — Cargill Dow LLC, a 50/50 partnership between Cargill and The Dow Chemical Company, is formed to develop, produce, and market PLA.

1997-1999 — DOE/EERE funds research conducted by Cargill, Lawrence Berkeley National Laboratory, and several additional industrial partners to develop a technology to improve separation of polar organic solutes produced by fermentation.

2000-2003 — DOE/EERE's Agriculture Industry of the Future (IOF) Program awards Cargill Dow an Enhanced Utilization project to further study the properties of PLA as they affect its industrial processing.

2001-2004 — DOE/EERE's IOF program awards Cargill Dow LLC a grant to develop a new technology that can make use of the five-carbon sugars currently left over from lignocellulosic feedstock processing.

2001-2005 — DOE/EERE awards Cargill Dow LLC a grant to develop a "biorefinery of the future."

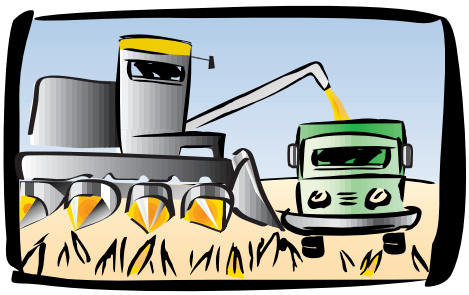
Innovative Industry-Government Research Partnership Continues

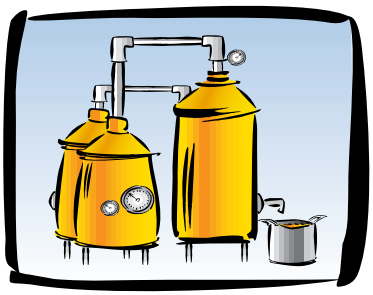
Cargill Dow LLC and the DOE continue to collaborate on research that will improve the efficiency of the plant and lead to new product applications. In addition to developing the industrial biorefinery concept, the DOE/EERE's Agriculture Industry of the Future (IOF) program is funding work to further study the chemical and physical properties of PLA.

Specifically, this work is concentrating on creating new grades of PLA that will be less expensive and easier to process, and improving performance attributes that will expand the potential applications for PLA in the marketplace. Cargill Dow LLC, NREL, and the Colorado School of Mines will be working together on this effort through 2003. Cargill Dow LLC and NREL are also working to develop new technologies that can make use of the five-carbon sugars currently left over from lignocellulosic feedstock processing.

Producing PLA

PLA is produced in five distinct steps:





Feedstock Processing

Feedstocks are processed using one of two methods:

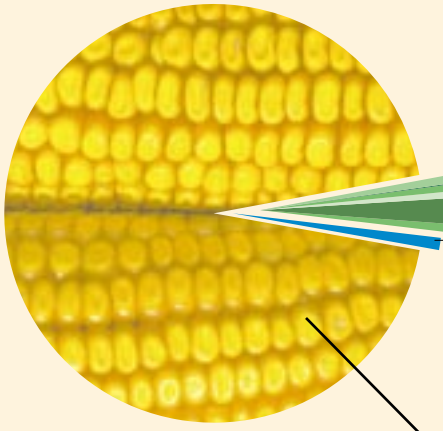
Traditional method Corn is wet-milled and processed to separate the starch (six-carbon sugars) from the raw material.

Future method The less expensive lignocellulosic material in corn fiber and corn stover is used to produce five- and six-carbon sugars. Lignin left over from this process can be burned as fuel or serve as a feedstock for phenol-formaldehyde resins.

Fermentation

The sugars produced by feedstock processing are fermented using special technologies to produce lactic acid.

A Very Good Investment: for Every $1M of Federal Money Invested in PLA, Private Industry Invested $16M



U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy grants to:

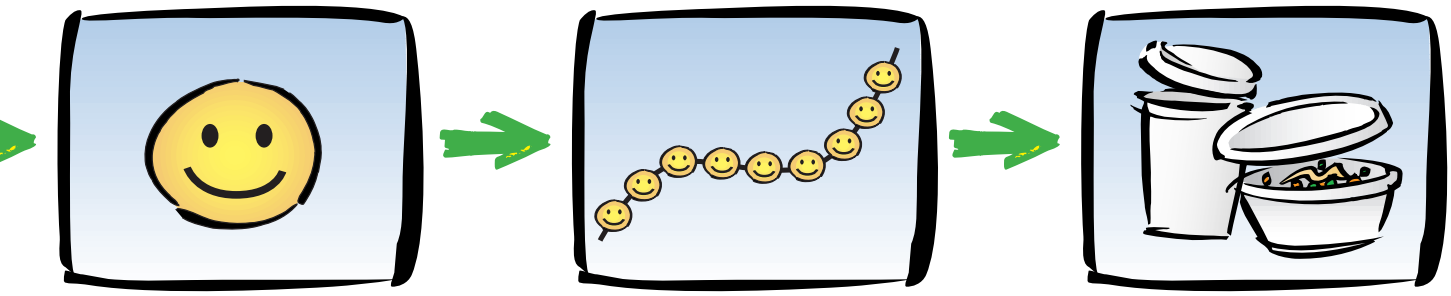
- Coors/NREL for expanded feedstocks $1.5M
- Cargill and partners for separation techniques $0.2M
- Cargill Dow LLC to develop Enhanced Utilization methods for feedstocks $1.2M
- Cargill Dow LLC to develop new fermentation technologies $1.2M
- Biomass Agricultural Products, Cargill Dow LLC, Iowa State University, and Midwest Labs to develop new corn harvesting techniques $4.6M
- Cargill Dow LLC/NREL for biorefinery research $1.5M

National Institute of Standards and Technology (NIST) grants to:

- Cargill Dow LLC, to study PLA properties $2.0M

Total Federal Investment: $12.2M

Total Cargill Dow LLC Investment: More than $200M



Separation and Purification

The monomer by-products of fermentation (carboxylic acids, alcohols, amino acids) are separated from the lactic acid to make it at least 99.5% pure.

Polymerization

The lactic acid is converted to a lactide dimer. The dimer is then polymerized further to yield high-molecular-weight PLA.

Product Finishing

PLA is finished using various processes, depending on how the product will be used. For the current product lines, PLA is woven as a fiber and cast in a variety of film thicknesses.

Other finishing techniques (depending on the intended product application) include extrusion of directionally oriented film and thermoforming into rigid containers.

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Awards

- In 2000, ***Popular Mechanics*** and ***Industry Week*** recognized PLA as one of the most influential developments of the past year.
- In 2001, Dr. Pat Gruber, Vice President and Chief Technology Officer for Cargill Dow LLC, received the **Discover Award for Environmental Innovation**, presented by the Christopher Columbus Fellowship Foundation. The Discover Award recognizes the creativity of the people, corporations, and institutions who have reached superior levels of ingenuity.

Publishing support services provided by the Information and Publishing Division of Argonne National Laboratory for the U.S. Department of Energy.